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Robert W. Scott, Xexuan Wang, Xin Lai, Yulun Wang. Late Albian cactus in shallow carbonate shelf, West Texas. *Carnets de Geologie*, 2016, 16 (12), pp.337-346. 10.4267/2042/60122 . hal-01333805

HAL Id: hal-01333805

<https://hal.science/hal-01333805>

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Late Albian cactus in shallow carbonate shelf, West Texas

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Abstract: Well-preserved vertical molds of a stalk-like fossil are in growth position in the upper part of the Upper Albian Fort Lancaster Formation exposed in West Texas. The Fort Lancaster Formation is the uppermost Albian carbonate unit deposited on the shallow water Barremian-early Cenomanian Comanche shelf. The Fort Lancaster represents one long-term transgressive-regressive cycle capped by a regional unconformity overlain by lower Cenomanian deeper water Del Rio Shale.

The erect stalk-like molds are up to 1 m tall and about 6 cm in diameter. The mold walls are composed of six pairs of angular ridges and grooves evenly spaced at an angle of 60° to each other. The ridge crests are dotted by paired ringed depressions with small central nodes; these negative impressions indicate the presence of oval rings with small depressions inside of each ring. The diameter of the stalk is the same at its base as at its top indicating that growth did not expand the organism but extended it upward. These stalk-like organisms appear to be rooted on disconformable bedding surfaces that were exposed to the atmosphere. Carbon isotope data shows the classic negative shift below subaerial contacts. Subsequently sea level rose and muddy carbonate sediment buried the stalk. The absence of original wall material suggests that the wall was composed of readily decayed or dissolved material such as organic matter or aragonite. Stalk-like organisms of this size and shape are rare and potential types are cacti, plant reeds, Porifera, or Scleractinian Cnidaria.

Key Words: Albian; Comanche shelf; plant-like fossil.

Citation: SCOTT R.W., WANG X., LAI X. & WANG Y. (2016).- Late Albian cactus in shallow carbonate shelf, West Texas.- *Carnets Geol.*, Madrid, vol. 16, no. 12, p. 337-346.

Résumé : *Un cactus de l'Albien supérieur en contexte de plate-forme carbonatée peu profonde, Ouest du Texas.*- Des moules verticaux bien conservés d'un fossile en forme de tige ont été trouvés en position de croissance dans la partie supérieure de la Formation de Fort Lancaster (Albien supérieur) affleurant dans l'ouest du Texas. La Formation de Fort Lancaster est une unité carbonatée de l'Albien terminal déposée dans les eaux peu profondes de la plate-forme de Comanche (Barrémien-Cénomanién inférieur). La Formation de Fort Lancaster représente un cycle transgressif-régressif de long terme coiffé d'une discontinuité régionale, elle-même recouverte par la Formation argileuse Del Rio déposée en eaux plus profondes du Cénomanién inférieur.

Les moules dressés en forme de tige font jusqu'à 1 m de hauteur et environ 6 cm de diamètre. Les parois des moules comportent six paires de crêtes anguleuses et de sillons. Ces crêtes régulièrement espacées font un angle de 60° entre elles. Les crêtes des rides sont ponctuées de dépressions annulaires appariées avec de petits nœuds en leur centre ; ces impressions en négatif indiquent la présence d'anneaux ovales au centre desquels figurent de petites dépressions. Le diamètre de la tige à sa base est le même qu'à son sommet, indiquant que l'organisme ne croissait pas radialement mais s'étirait vers le haut. Ces organismes en forme de tige semblent prendre racine sur des surfaces de discordance émergives. Les données du carbone isotopique montrent une baisse négative classique sous les surfaces d'émersion. Par conséquent, à la faveur d'une baisse du niveau marin, la tige a été enfouie dans des sédiments boueux carbonatés. L'absence du matériel originel de la paroi laisse penser que cette dernière était composée d'une matière facilement putrescible ou soluble, telle que de la matière organique ou de l'aragonite. Les organismes en forme de tige de cette taille et de cette morphologie restent rares ; les candidats envisageables sont des cactus, des roseaux, des porifères, ou des cnidaires scléractinaires.

Mots-clefs : Albien ; plate-forme de Comanche ; fossile phytoïde.

Introduction

Well-preserved vertical molds of a fossil stalk-like organism are in growth position in the upper part of the Upper Albian Fort Lancaster Formation exposed in U.S. 290 road cuts about 10 km (6 mi) southeast of its intersection with I-10 and about 24 km (15 mi) east of Sheffield, Texas (Fig. 1) (N30°40.720', W101°40.372',

Crocket County, Texas). The steep road descends into the Pecos River Valley and these outcrops are the type section of the Fort Lancaster (SMITH *et al.*, 2000). During field work in 2013 Xexuan WANG noticed these unusual molds. Subsequent study convinced the authors that these vertical molds were fossils that deserved careful description.

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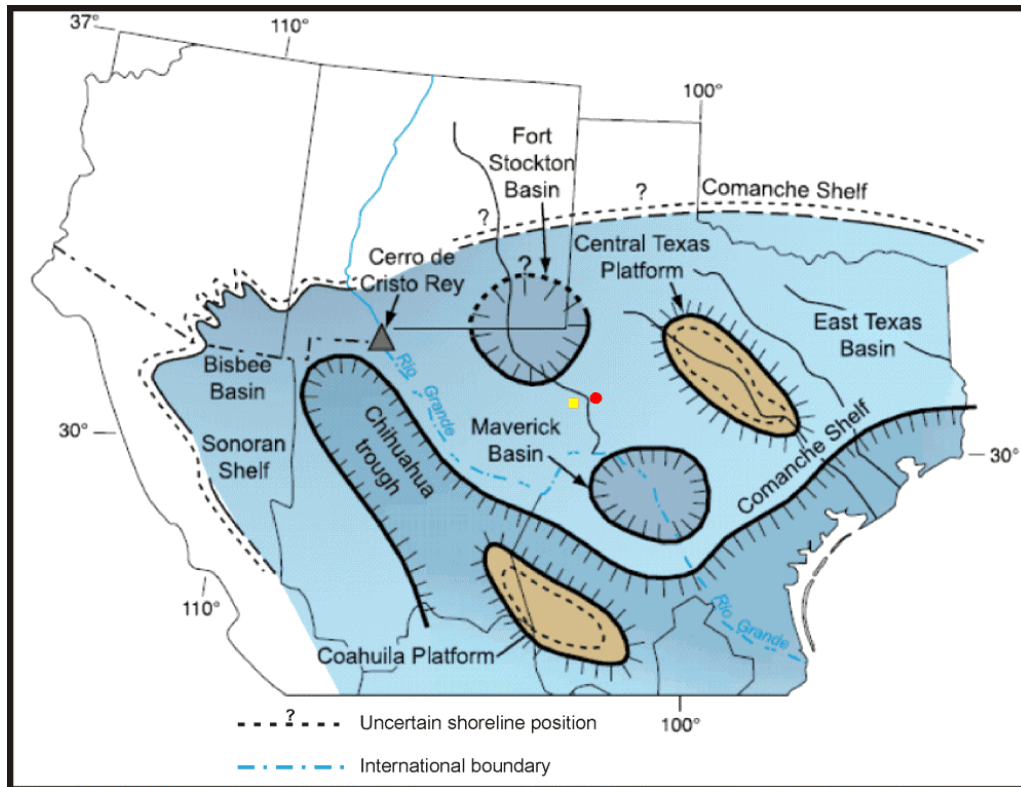
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Published online in final form (pdf) on May 19, 2016

[Editor: Bruno GRANIER]



◀ **Figure 1:** Paleogeographic map of the Albian Comanche shelf showing location of outcrop of Fort Lancaster Formation on U.S. 290 and fossil molds (red dot); yellow box is site of Sheffield (after SCOTT, 2003).

The Fort Lancaster Formation is the uppermost Albian carbonate unit deposited on the Barremian-early Cenomanian Comanche shelf that extended from Florida to Arizona on the northern margin of the proto-Gulf of Mexico (ROSE, 1972; SMITH *et al.*, 2000; SCOTT & KERANS, 2004). The purpose of this paper is to describe the stalk-like molds, and to propose that a cactus was the most likely originator of these molds.

Stratigraphic data

The Fort Lancaster Formation is a dominantly limestone lithostratigraphic unit exposed north and south along the Pecos River valley in West Texas and in adjacent streams flowing to the Rio Grande River at the International border of the United States and Mexico (SMITH *et al.*, 2000). A late Albian age is defined by ammonites in the basal part and by caprinid rudists and benthic foraminifers in the upper part of the formation (YOUNG, 1966; SCOTT, 2002a, 2002b; SCOTT & KERANS, 2004). The Fort Lancaster represents one, long-term, transgressive-regressive cycle capped by a regional unconformity overlain by the lower Cenomanian deep shelf Del Rio Shale in some places and by the lowermost Cenomanian Buda Limestone where the Del Rio has pinched out (SMITH *et al.*, 2000; LAI, 2014; Y. WANG, 2014).

The Fort Lancaster Formation is divided into a basal shale and limestone interval about 15 m thick that is correlated with the Burt Ranch Member in Central Texas (ROSE, 1972; SMITH *et al.*, 2000). The base of the Burt Ranch is a

regional, disconformable sequence boundary that correlates with lower-upper Albian AI SB Wa 1 in North Texas (SCOTT *et al.*, 2003; GARGILI, 2013; LAI, 2014; Y. WANG, 2014). In the Fort Lancaster road section the top of the underlying Fort Terrett Formation is a bored, iron-stained contact; a 2 ppm positive carbon isotope shift in the uppermost 1 m of the Fort Terrett is evidence that the contact at this site was sub-aerially exposed (GARGILI, 2013; LAI, 2014).

The uppermost 15 m of the Fort Lancaster Formation is composed of six m-scale shoaling-up carbonate cycles, some of which are separated by iron-stained contacts with red clay (SMITH *et al.*, 2000; LAI, 2014) (Figs. 2 - 3). These cycles were deposited during the aggrading highstand relative sea-level. The stalk-like fossil molds are found in the upper 7 to 8 m of the Fort Lancaster in basal and upper parts of carbonate cycles 2, 3, 4, 5, and 6. Carbonate microfacies of cycle 4 grade from bioclastic packstone with rudist and echinoderm bioclasts at the base to wackestone with miliolid and other benthic foraminifera at the top. Cycle 5 is composed of bioclastic wackestone with benthic foraminifera, requienid bivalves, gastropods, calcareous algae, ostracodes, and echinoderm clasts. Carbonate facies are fully described by GARGILI (2013) and LAI (2014). These carbonate lithologies suggest that the cycles were deposited below local wave base in an interior shelf lagoon and shoaled up to sea level. About 80 km south was the high-energy Devils River shelf margin trend on the northern margin of the McKnight Basin. The shallow shelf extended

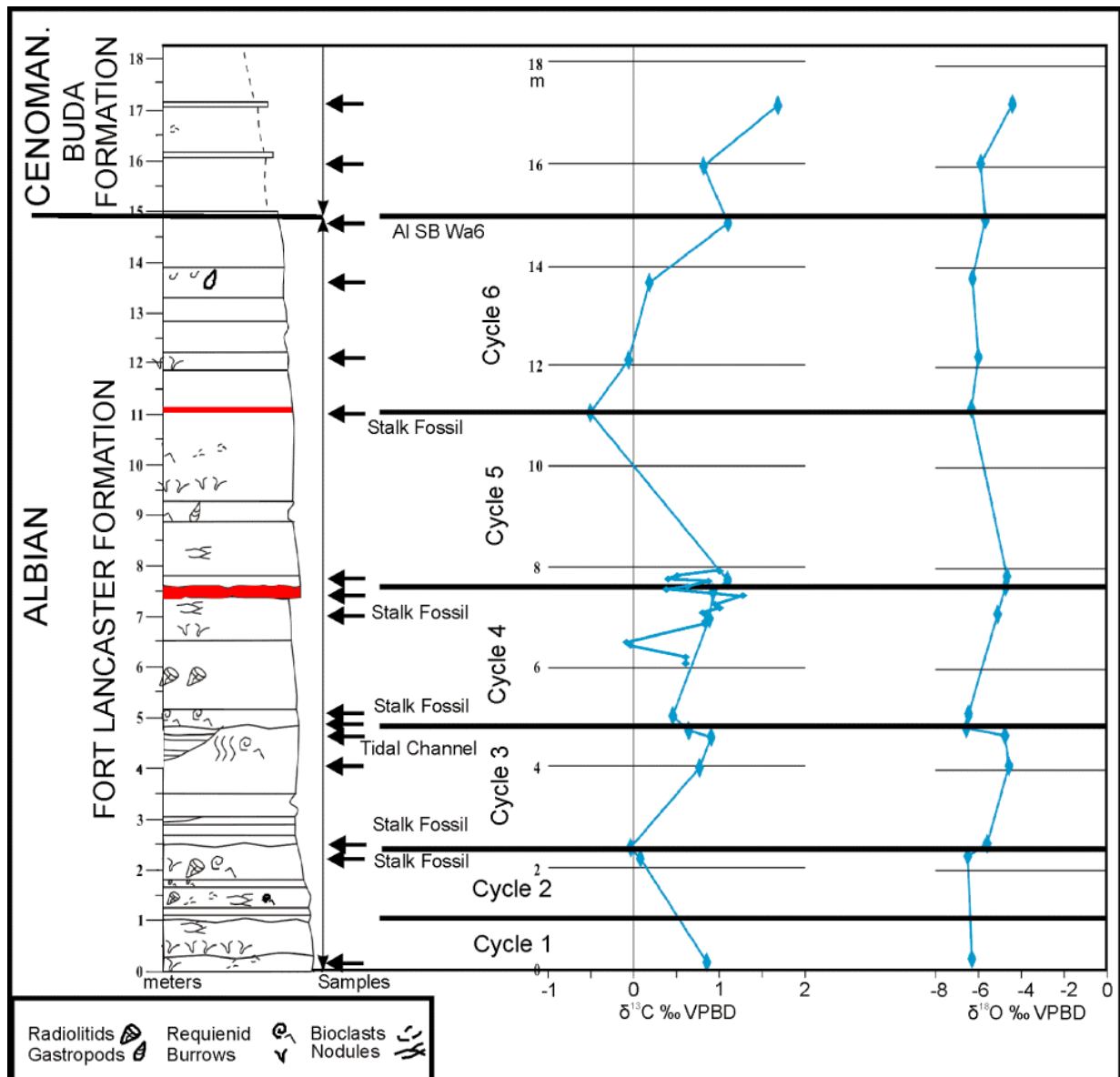


Figure 2: Measured section of upper part of Fort Lancaster road cut showing position of stalk fossils and meter-scale depositional cycles; arrows indicate positions of isotope sample set 1; isotope sample set 2 are smaller diamonds spanning red bed (black). Contact between Fort Lancaster and Buda formations is regional Albian sequence boundary Wa 6 defined in Fort Worth section between Main Street and Grayson formations (SCOTT *et al.*, 2003).

westward and eastward at least 100 km in each direction; northward lay shoreline. Relative sea-level fall exposed these beds to subaerial conditions, which is indicated by the positive carbon isotope shift (Fig. 2). This muddy surface was available to be occupied by terrestrial plants.

At the contact between cycles 4 and 5 is a reddish, iron-rich, bioclastic mudstone up to 15 cm thick. The top of cycle 4 is red stained, sharp and irregularly wavy with relief of 5-8 cm. The surface is scalloped by simple, low-relief bowls ranging in width from 5 to 20 cm and up to 5 cm deep. These may be footprint impressions; an alternative origin may be simple paleokarst depressions that evolved from potholed paleokarst (VANSTONE, 1998). A pene-contemporaneous fracture extends downward

1.7 m from the base of one karst depression to the base of cycle 4 (Fig. 4). This fracture is filled mainly with red clay and a few pebble- to cobble-sized limestone clasts. Evidently the muddy carbonate lithified early and fractured during subaerial exposure; the fracture then was filled by soil, bioclasts, and limestone breccia. A positive carbon isotope shift of 0.64 ppm from base to top of the cycle is overlain by a negative shift of 1.0 ppm at the base of cycle 5 (Fig. 2). These data support the interpretation that the contact between cycles 4 and 5 was subaerially exposed. This red bed has been mapped in many sections in the Pecos River valley and farther east where the color changes to green and black (SMITH *et al.*, 2000; HALLEY & ROSE, 1977; ROSE, 1972; Y. WANG, 2014).

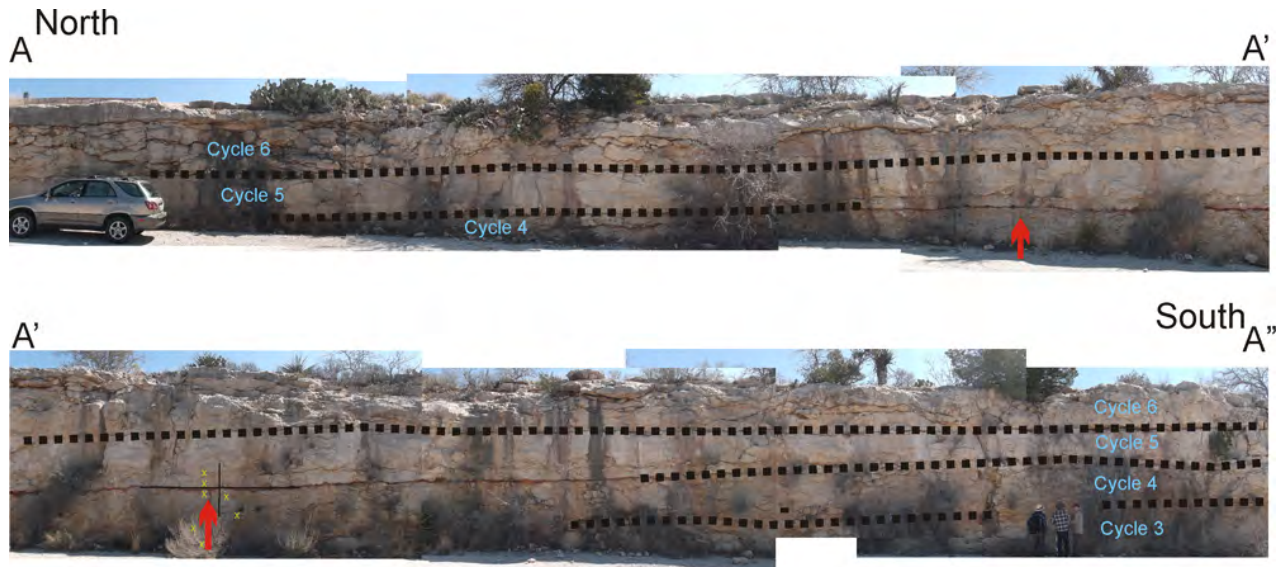


Figure 3: East face of roadcut U.S. 290 below parking site. Note three persons in lower right for scale. Dotted lines define bedding cycles 4-7 in the uppermost 10 m of the Fort Lancaster Formation. Red arrows point to molds of fossil plants. Yellow 'Xs' mark the second set of isotope samples.

Description of cactus fossil molds

The stalk-like molds are columnar cylindrical stems standing up to 1 m tall and are about 6 cm in diameter (Fig. 4.A-B); they are interpreted to be molds of a cactus. Branches are not evident. The mold walls are composed of evenly spaced angular ribs and grooves (Fig. 4.C) similar to the modern genus, *Cereus* among others. Six pairs of ribs and grooves are arranged at an angle of 60° to each other (Fig. 4.D-E). The angle between the faces was measured from the plasticene mold which was formed by impressing the clay into the mold; however, it was slightly distorted by extraction and subsequent handling. Thus the measurements vary on different profiles of the cast and have been averaged ((Fig. 4.F-1)). The cross section profile was then constructed from these measurements assuming that the fossil outline was circumscribed by a circle (Fig. 4.F-2). Ribs and flutes of some specimen molds are less well expressed suggesting that these specimens were more inflated by water than others as succulents may be.

The rib crests are dotted by paired depressions with small nodes; these negative impressions indicate the presence of oval rings with small depressions inside of each ring (Fig. 4.C). The sets of rings and pits are spaced about 1 cm apart along the rib crests. These dimensions are approximate because the structures are preserved as negative molds. These structures are similar to cactus tubercles and areoles from which spines grow. The bases of two molds are flat and apparently with no indication of rootlets or taproots (Fig. 4.D & F). The diameter of the stalk is the same at its base as at its top indicating that growth did not expand the organism but extended it upward. The absence

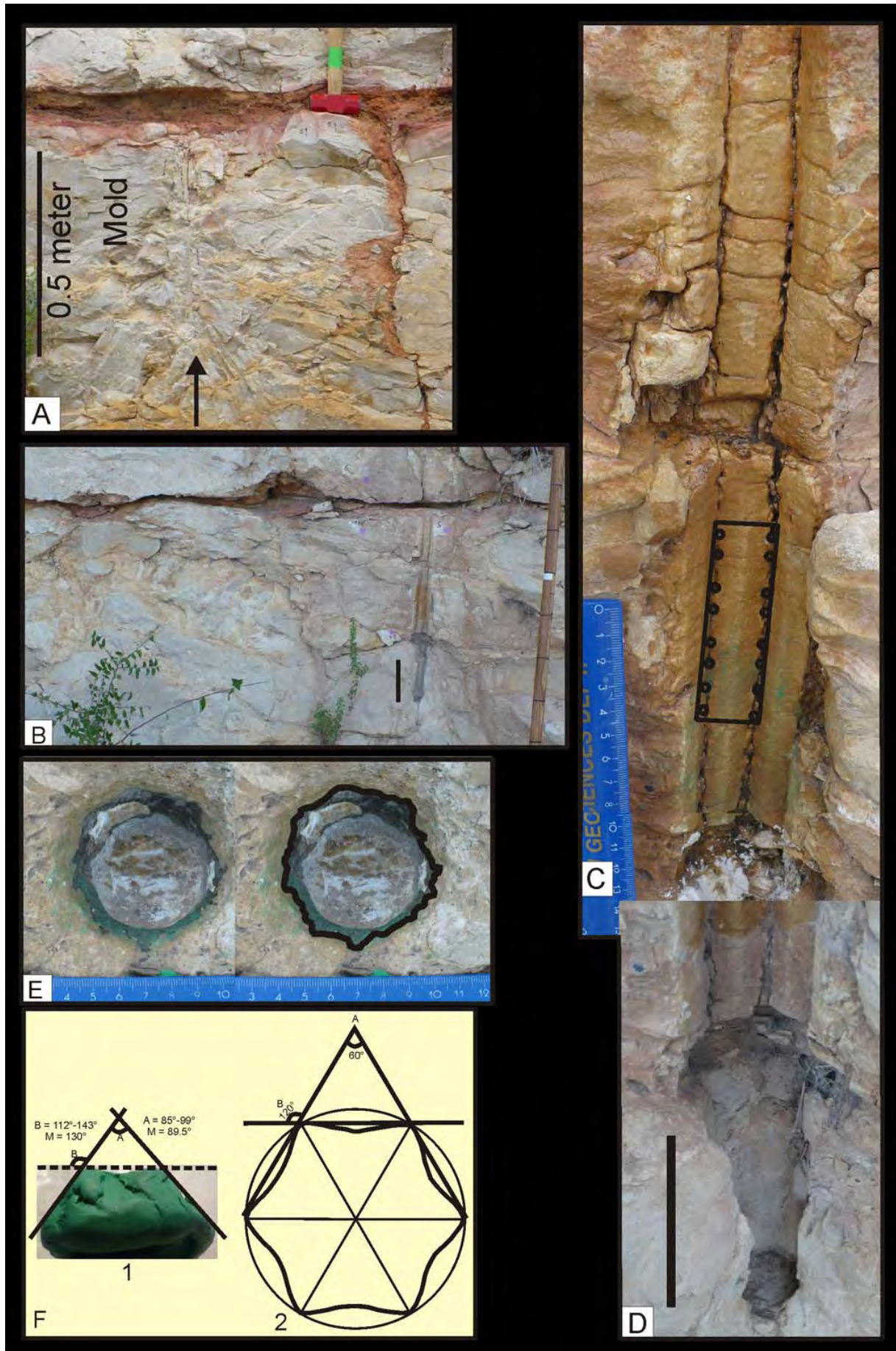
of original wall structure suggests that the wall was composed readily decayed or dissolved material such as organic matter or aragonite.

If these molds were formed by chlorophyll-bearing plants, they potentially would indicate shallow water depth within the photic zone. An alternative explanation is that these plants grew in the exposed marine mud proximal to the coastline between periodic inundations.

Taphonomy

The mode of preservation of these molds in shallow-water carbonate sediment is a dilemma. At least two hypotheses are reasonable. 1) The specimens grew on the exposed substrate and were subsequently buried. 2) The specimens were buried as they grew. This latter process seems untenable if the cactus-like plant was not salt-tolerant and required a dry terrestrial habitat and fresh water as modern cacti do.

► **Figure 4:** Stratigraphic setting and morphology of cactus-like fossils in east-side road cut of U.S. 290. A, Fossil mold specimen top of cycle 4 overlain by red clay bed; note shallow depressions on top of bed 4 into which penecontemporaneous fracture ends. B, C, D. Fossil mold specimen 1 at top of cycle 5. C, D. Mold of stalk-like fossil 1 showing three faces and flat base; note outline of pores on angular ridges. E. Natural and outlined views into mold base showing poorly preserved ridges and grooves; note apparent absence of root-like structures in base. F. Measurement of mold faces in clay cast and reconstruction of circular outline of complete six-part symmetry of fossil; 'M' = mean angle. The 89.5° angle was measured on the distorted clay cast; to accommodate six facets within a 360° circle, the angle is projected at 60° .



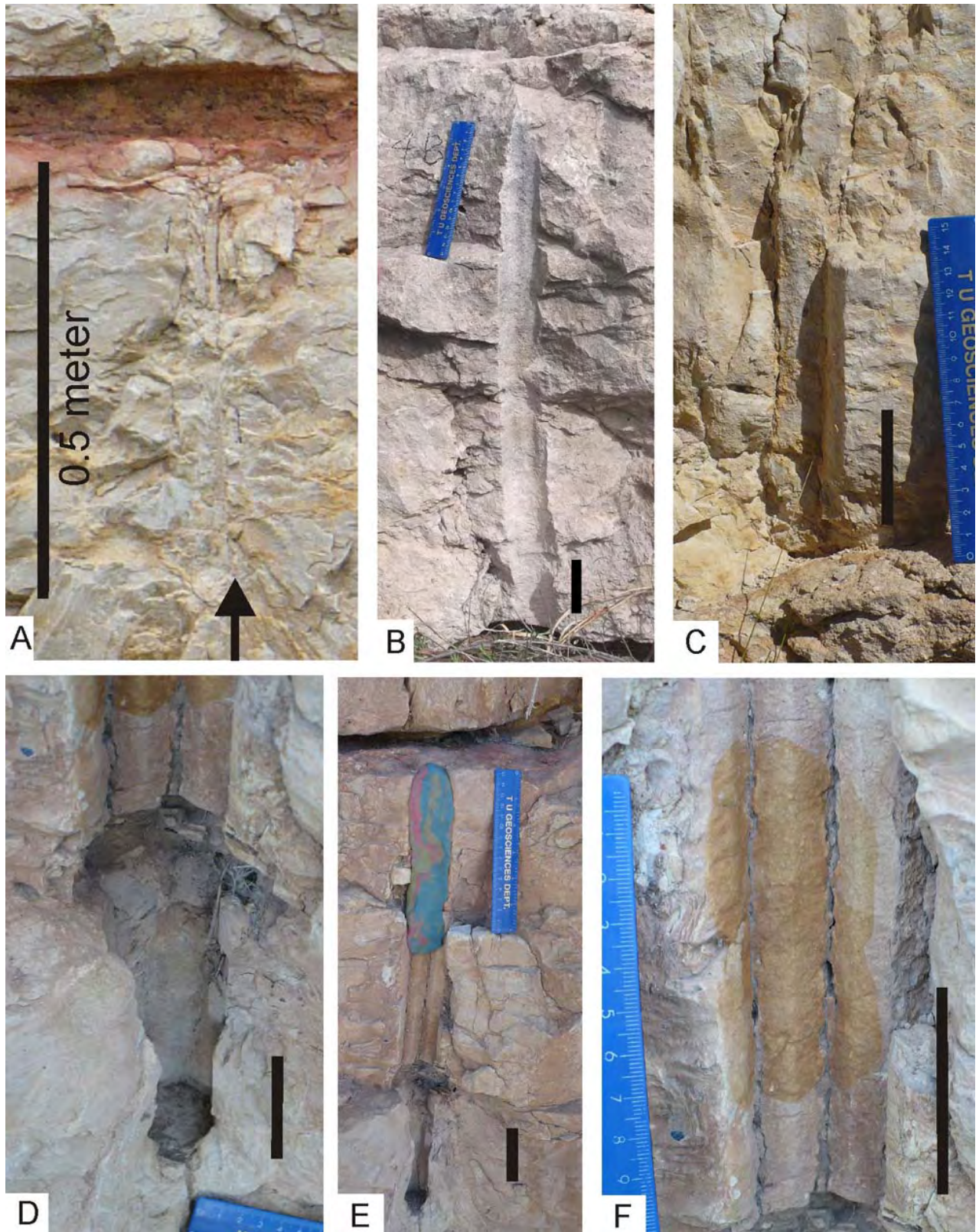


Figure 5: Variations among stalk-like molds. A. Mold at top of cycle 4 truncated by red paleosol. B. Slightly curved specimen at basal contact of cycle 4. C. Mold in upper part of cycle 2. D-F. Closeups of mold in Figure 4; C. Base of mold buried in limestone; E. Overview of mold. F. closeup of mold facet with node impressions. Scale bars are 5 cm.

The bases of many stalk-like molds are set on exposure contacts at top of meter-scale depositional cycles. Also some terminate at the red clay exposure contact at tops of cycles. These relationships suggest that the stalk-like organisms began growing on the subaerial surface of the vast exposed surface. Subsequently sea level rose and sedimentation buried the stalk, which was terminated by subaerial exposure of the concurrent cycle. The organism terminated at the subaerial surface either ending growth or it was truncated during exposure.

This first scenario requires that the stalk remained erect as sea level deepened and muddy carbonate sediment buried it. Wave energy, tides or other currents would have been very minimal so that the stalk was not toppled during the beginning of rise. The virtual absence of water movement is conceivable across the 100 km+ wide flat substrate as sea level rose slowly and water depth was on the order of centimeters. If sedimentation rate was on the order of 6000 cm/1,000 year as it has been on the leeward side of the Great Barrier Reef (ENOS, 1991, p. 73), then the meter-tall plant would be buried in 16-17 years.

Interpretation

Stalk-like fossil organisms of this size and shape are rare; potential candidates are reeds such as cacti, and marine Porifera and Scle-ractinian Cnidaria. Early Cretaceous Angiosperm evolution has been documented using molecular data combined with morphology of leaves and pollen (DOYLE, 2012; DOYLE & UPCHURCH, 2014) however none have a similar stalk-like morphology. Early Albian lineages were "Nymphaeales, Austrobaileyales, Chloranthaceae, magnoliids (Canellales and Magnoliales), monocots, and eudicots" (DOYLE & UPCHURCH, 2014). During Middle and Late Albian angiosperms diversified into modern clades. In Europe Barremian-Albian plant impressions show that angiosperms progressively diversified their ecological habitats from braided rivers and freshwater swamps to flood plains, levees, estuaries, and salt marshes (COIFFARD *et al.*, 2007).

Early Cretaceous gymnosperms and angiosperms were widespread and diverse on the Comanche shelf on the northern Gulf of Mexico. The fossil plant record of the Comanche shelf is documented primarily by spore and pollen and sparse leaves and wood in strand plain and alluvial plain sandstone (RETALLACK & DILCHER, 1986). The conifers *Weichselia* and *Frenelopsis*, which grew in brackish swamps (COIFFARD *et al.*, 2007), together with seed ferns and angiosperms are preserved in chert of the middle-upper Albian Edwards Formation (SERLIN, 1982). Pollen and spore microfossils in marine shale-marl of the upper Albian Washita Group indicate

that a diverse plant assemblage of Lycophytea, Pterophyta, Gymnospermae, and Angiospermae populated the northern shoreline of the Comanche shelf (HEDLUND, 1966; HEDLUND & NORRIS, 1968; WINGATE, 1980; SRIVASTAVA, 1981). Gymnosperm pollen was most abundant in the upper Albian Denton Formation, Washita Group, in southern Oklahoma and angiosperms were about ten percent of the assemblage. Westward in the Fort Stockton area land-derived spores and pollen were abundant in the Middle Albian Fort Terrett Formation and in the upper part of the Fort Lancaster Formation, Washita Group (SCOTT & KIDSON, 1977), but cactus pollen has not been reported. The marine shelf supported diverse calcareous algae (JOHNSON, 1968), none of which has a columnar morphology.

A modern fresh-water, aquatic plant that may be analogous is *Ceratophyllum* or hornwort of the Family Ceratophyllaceae, which has a cosmopolitan Paleocene to Miocene fossil record (HERENDEEN *et al.*, 1990). The stems are much narrower than the Fort Lancaster mold and have narrow spiny leaves originating from nodes on the stem (HERENDEEN *et al.*, 1990, Figs. 19-20; DILCHER & H. WANG, 2009). Fossil species are differentiated by their ovate spiny fruits. Modern species grow up to 3 m in length and float below the water surface. The stems do not have roots and leaf whorls attach to nodes on the stem. Phylogenetic analyses suggest that herbaceous groups such as *Ceratophyllum* are near the base of the angiosperm clade (DOYLE, 1996, 2012; DOYLE & UPCHURCH, 2014). DOYLE and UPCHURCH suggested that these molds could be trace fossils rather than plant molds (personal communication, December 21, 2015). However the repetition of morphology in multiple molds and the uniform structure indicates that these are molds of an organism and not traces made by the variable behavior of an animal.

The morphology of these molds and habitat setting on an exposed carbonate substrate during low sea level are consistent with a cactus plant. However that these were molds of cactus plants seems improbable because no fossils or undisputed cactus pollen are known (NYFFELER, 2002; NYFFELER & EGGELI, 2010). Two current hypotheses propose that Cactaceae evolved either in the Late Cretaceous or more likely in the younger part of the Paleogene about 30 myr ago. An Eocene Opuntoid cactus, about 55-34 Ma old, was described from Utah (CHANEY, 1944). If these molds were formed around cacti, these would be evidence of the oldest cactus, which would alter the presumed evolutionary history. Alternatively, these plants may have been members of an early clade that became extinct and unrelated to Cactacea as understood today.

An origin by a stalk-shaped marine animal is unlikely because this morphology is uncommon. Although Early Cretaceous Porifera species are poorly known on the Comanche shelf, known species are small, nodular or encrusting; none are erect, six-sided structures. Spicules are in chert nodules of the Albian Edwards Formation (MERRILL, 1895), and sponges have been reported in the lower Cenomanian Buda Formation (ADKINS, 1928). Two small nodular sponge species were described from the Lower Albian Mural Formation in Arizona and Sonora, one of which was noted also in the Fredericksburg shelf margin facies in Texas (RIGBY & SCOTT, 1981). Encrusting stromatoporoids have been noted in shelf margin buildups but not fully described (SCOTT, 1990).

Scleractinian corals are diverse and widespread in Comanchean strata of North America (WELLS, 1933; FILKORN, 2003). Both colonial and solitary species are known. The six-part radial symmetry is the diagnostic feature and skeletons were composed of aragonite. However none have tall, stalk-like morphologies and most are preserved as secondary calcite not as molds.

Conclusions

Well preserved vertical molds of a fossil reed-like plant are in growth position in the upper aggrading part of the Upper Albian Fort Lancaster Formation exposed in the Pecos River valley, West Texas. The Fort Lancaster Formation is the uppermost Albian carbonate unit deposited on the Barremian-early Cenomanian Comanche shelf. The Fort Lancaster Formation is dominantly limestone of late Albian age defined by ammonites in its basal part and by caprinid rudists and benthic foraminifers in its upper part. The Fort Lancaster represents one long-term transgressive-regressive cycle capped by a regional unconformity overlain by the lower Cenomanian Limestone. The upper 15 m interval is composed of six aggrading cycles separated by subaerial contacts representing times when sea level fell exposing the substrate to the air. These vast supratidal surfaces were populated by primitive cacti and possibly other plants.

The stalk-like molds are erect standing up to 1 m tall and about 6 cm in diameter. The mold walls are composed of six evenly spaced angular pairs of ridges and grooves arranged at an angle of 60° to each other. The ridge crests are dotted by paired depressions with small nodes; these negative impressions indicate the presence of oval rings at the nodes with small depressions inside of each ring. Roots are not preserved and the diameter of the molds is the same at the base as at the top. Apparently the organism began to grow on the exposed substrate and subsequently was buried as carbonate mud

accumulated around it. The absence of original wall structure suggests that the wall was composed of readily decayed or dissolved material such as organic matter or aragonite. The most likely candidate as the original organism is a cactus.

Acknowledgments

The University of Tulsa Office Of Research and Sponsored Programs and the Geosciences Department generously supported research by Damla GARGILI, Xin LAI, Yulun WANG, and Robert SCOTT. Field expenses were partly supported by Precision Stratigraphy Associates. Email discussions with J.A. DOYLE and G.R. UPCHURCH, Jr, prompted multiple candidates. I am grateful to the reviewers, Bruno FERRÉ, Christopher BALDWIN and Steve HASIOTIS, who noted omissions and offered ways to improve the manuscript: Steve HASIOTIS noted the cactus similarity.

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Late Albian cactus in shallow carbonate shelf, West Texas

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Abstract: Well-preserved vertical molds of a stalk-like fossil are in growth position in the upper part of the Upper Albian Fort Lancaster Formation exposed in West Texas. The Fort Lancaster Formation is the uppermost Albian carbonate unit deposited on the shallow water Barremian-early Cenomanian Comanche shelf. The Fort Lancaster represents one long-term transgressive-regressive cycle capped by a regional unconformity overlain by lower Cenomanian deeper water Del Rio Shale.

The erect stalk-like molds are up to 1 m tall and about 6 cm in diameter. The mold walls are composed of six pairs of angular ridges and grooves evenly spaced at an angle of 60° to each other. The ridge crests are dotted by paired ringed depressions with small central nodes; these negative impressions indicate the presence of oval rings with small depressions inside of each ring. The diameter of the stalk is the same at its base as at its top indicating that growth did not expand the organism but extended it upward. These stalk-like organisms appear to be rooted on disconformable bedding surfaces that were exposed to the atmosphere. Carbon isotope data shows the classic negative shift below subaerial contacts. Subsequently sea level rose and muddy carbonate sediment buried the stalk. The absence of original wall material suggests that the wall was composed of readily decayed or dissolved material such as organic matter or aragonite. Stalk-like organisms of this size and shape are rare and potential types are cacti, plant reeds, Porifera, or Scleractinian Cnidaria.

Key Words: Albian; Comanche shelf; plant-like fossil.

Citation: SCOTT R.W., WANG ~~X.~~ Z., LAI X. & WANG Y. (2016).- Late Albian cactus in shallow carbonate shelf, West Texas.- *Carnets Geol.*, Madrid, vol. 16, no. 12, p. 337-346.

Résumé : *Un cactus de l'Albien supérieur en contexte de plate-forme carbonatée peu profonde, Ouest du Texas.*- Des moules verticaux bien conservés d'un fossile en forme de tige ont été trouvés en position de croissance dans la partie supérieure de la Formation de Fort Lancaster (Albien supérieur) affleurant dans l'ouest du Texas. La Formation de Fort Lancaster est une unité carbonatée de l'Albien terminal déposée dans les eaux peu profondes de la plate-forme de Comanche (Barrémien-Cénomanién inférieur). La Formation de Fort Lancaster représente un cycle transgressif-régressif de long terme coiffé d'une discontinuité régionale, elle-même recouverte par la Formation argileuse Del Rio déposée en eaux plus profondes du Cénomanién inférieur.

Les moules dressés en forme de tige font jusqu'à 1 m de hauteur et environ 6 cm de diamètre. Les parois des moules comportent six paires de crêtes anguleuses et de sillons. Ces crêtes régulièrement espacées font un angle de 60° entre elles. Les crêtes des rides sont ponctuées de dépressions annulaires appariées avec de petits nœuds en leur centre ; ces impressions en négatif indiquent la présence d'anneaux ovales au centre desquels figurent de petites dépressions. Le diamètre de la tige à sa base est le même qu'à son sommet, indiquant que l'organisme ne croissait pas radialement mais s'étirait vers le haut. Ces organismes en forme de tige semblent prendre racine sur des surfaces de discordance émerives. Les données du carbone isotopique montrent une baisse négative classique sous les surfaces d'émergence. Par conséquent, à la faveur d'une baisse du niveau marin, la tige a été enfouie dans des sédiments boueux carbonatés. L'absence du matériel originel de la paroi laisse penser que cette dernière était composée d'une matière facilement putrescible ou soluble, telle que de la matière organique ou de l'aragonite. Les organismes en forme de tige de cette taille et de cette morphologie restent rares ; les candidats envisageables sont des cactus, des roseaux, des porifères, ou des cnidaires scléractinaires.

Mots-clefs : Albien ; plate-forme de Comanche ; fossile phytoïde.

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Published online in final form (pdf) on May 19, 2016 [Erratum: Published on June 19, 2016]

[Editor: Bruno GRANIER]